

## A novel littoral habitat from a riparian invader: implications on stream secondary production and riparian management

JMCK Jayawardana

School of Science and Engineering, University of Ballarat, Victoria 3353.  
Department of Natural Resources, Faculty of Applied Sciences,  
Sabaragamuwa University of Sri Lanka. Email: jayawardanack@appsc.sab.ac.lk

### Abstract

Understanding the functional role of invasive species is important for better management of ecosystems. Exotic willows (*Salix* spp.) are widespread riparian trees of temperate Australia and New Zealand. Despite being classed as weeds of national significance, little is known of their effects on ecosystem function. Extensive growth of complex willow root mats in streams they infest has created a novel littoral habitat. Spatial and temporal changes of macroinvertebrates in willow root mats and bare bank habitats were examined in three central Victorian rivers to gain an understanding of their effects on this faunal group. Macroinvertebrate richness, abundance, biomass and diversity were significantly higher ( $p < 0.05$ ) in willow root habitats compared to open bank habitats. This suggests willow root mats have created a new niche for macroinvertebrate communities in willow-infested streams in Australia and emphasises the need for concurrent habitat enrichment programs when removal of exotic vegetation takes place. (*The Victorian Naturalist* 132 (4) 96–107)

**Keywords:** biodiversity, invasive taxa, macroinvertebrates, *Salix*, willow roots

### Introduction

Habitat diversity has been correlated with high macroinvertebrate diversity (Schiemer *et al.* 1991; Minshall 1988; Harper *et al.* 1992; Minshall and Robinson 1998) suggesting loss of habitat complexity due to river channelisation and removal of riparian vegetation, which will adversely affect macroinvertebrate richness, abundance, biomass and diversity. This suggests that care is required where clearing of already established exotic riparian vegetation is undertaken. Recognition of available habitat structures or the presence of surrogate habitat structures is important for appropriate management.

There are many examples from marine and freshwater environments where a positive increase in diversity has been achieved through habitat manipulations. Artificial reefs and other habitat structures are widely used to improve marine habitats to improve fisheries (Russell 1976; Talbot *et al.* 1978; Burchmore *et al.* 1985). Bell *et al.* (1985; 1987) used artificial sea grass units to increase recruitment of post larval and juvenile fish and crustaceans to estuaries around Sydney, NSW. Koehn (1987) showed increase in fish abundance in a stretch of the Owens River, in north-eastern Victoria, after it had been seeded with large rocks. Snags have been identified as important habitat for inver-

tebrate and vertebrate biodiversity (Borchardt 1993; Phillips and Kilambi 1994). Habitat enhancement through planting of willow *Salix* sp. and Common Reed *Phragmites australis* in off-channel bays in parts of the Huntspill River, Somerset, England, resulted in a significant increase in abundance and diversity of fish (Langler and Smith 2001).

Willows were introduced to Australia during the early 19th century and became naturalised. They have spread across approximately 30 000 km of the 68 000 km river frontage in Victoria (Ladson *et al.* 1997). The impacts of willows on stream channel morphology have been widely researched (e.g. Young 1980; Ladson *et al.* 1997); but little research has been carried out to understand their effects as habitat. Willows have a characteristic complex root system that often grows into the stream channel and is different from the root system of most native riparian tree species. Where willows are dominant, their roots cover a large area of the littoral zone of channels. These root mats can be considered as a novel littoral habitat. Studies in the Murrumbidgee River near Wagga Wagga, NSW (Robertson 1993) revealed that exposed inundated roots formed patches of habitat providing shelter, food and oviposition sites for

diverse aquatic macroinvertebrates while bare banks were inhabited by only thinly scattered oligochaetes and chironomids. Boulton and Lloyd (1991) also found bare banks to be poor microhabitat in the lower Murray River compared to root habitats. Their conclusions were based on a study of only two seasons of the year. Jayawardana and Westbrook (2010) and Jayawardana (2011) compared macroinvertebrate communities of root habitats provided by willows with those provided by native vegetation and found differences in species composition. No comprehensive study has been carried out to investigate the contribution of willow roots as a habitat for macroinvertebrate communities in places where other vegetation is lacking. In the management of invasive riparian vegetation, it is important to understand the habitat function of these introduced species and their ecosystem functions to aid management and habitat remediation. Therefore, the objective of this study was to investigate how macroinvertebrate communities use willow root mats as a habitat compared to open bank habitats. Macroinvertebrate richness, abundance, biomass, diversity and assemblages associated with willow root mats and open bank habitats were compared in three Central Victorian streams during summer, autumn, winter and spring of 2004.

## Materials and methods

### Study sites

Birch Creek, located in the north central region of Victoria, is a major tributary of the northward flowing Tullaroop Creek system in the upper catchment of the Loddon River. The riparian vegetation includes native *Eucalyptus* spp., *Acacia* spp., *Callistemon* spp., *Leptospermum* spp. and exotic *Salix* spp. (willows), with intermittent reed-dominated stretches. The dominant land uses adjacent to the creek are grazing and cropping. Jim Crow Creek is also a tributary of the Loddon River, containing native vegetation, exotic willows and intermittent reed beds. It flows largely through public land. The East Moorabool is a branch of the Moorabool River, which originates in the Great Dividing Range in Central Victoria. It flows through native forest and agricultural areas and has stretches dominated by willows and native vegetation (Fig.1).

### Sampling

Two sites (100 m reach) were selected for sampling in each of three rivers (4th to 5th order), each site having stretches of willows and bare banks. Six samples were collected from each habitat type. Sampling was carried out during summer, autumn, winter and spring using a 20 cm × 20 cm horizontal metal frame attached to a sampler with a 250 µm mesh net. The area inside the sample frame was excavated to 5 cm depth and the whole sample, together with the portion retained in the net as a result of site disturbance, was collected and sealed in a polythene bag. All samples were transported to the laboratory for sorting. Dissolved oxygen, pH, conductivity, temperature and flow also were recorded in each instance. In the laboratory, samples were sieved (minimum sieve size 250 µm) and macroinvertebrates were separated and preserved in 70% alcohol. The species present in each sample were identified to the lowest possible taxonomic level (Cranston 1996; CSIRO 1999; Gooderham and Tsyrlin 2002; Hawking and Theischinger 1999). The live willow roots were separated and the remaining fraction of the sample was separated into coarse particulate matter fraction (CPOM) (>1 mm) and fine particulate matter fraction (FPOM) (1 mm–250 µm), air dried for 24 hrs and oven dried at 105°C until constant weight was attained. After recording the dry weight, each fraction was ashed at 550°C for six hours and ash free dry weight (AFDW) was recorded for each fraction. CPOM and FPOM content were calculated for each sample and percentages of CPOM and FPOM were calculated.

### Analysis

A total of 288 samples were collected over the four seasons. The data were analysed using multifactorial ANOVA with season, river and habitats within sites as main effects. Differences in species richness, total abundance and Shannon Diversity Index (SDI) between habitats were assessed using multifactorial ANOVA in the 'R' package (R Development Core Team 2004). Total abundance values were log transformed [ $\log(1+x)$ ] before analysis to counteract the effect of highly dominant taxa.

Macroinvertebrate community assemblage differences were assessed using Canonical

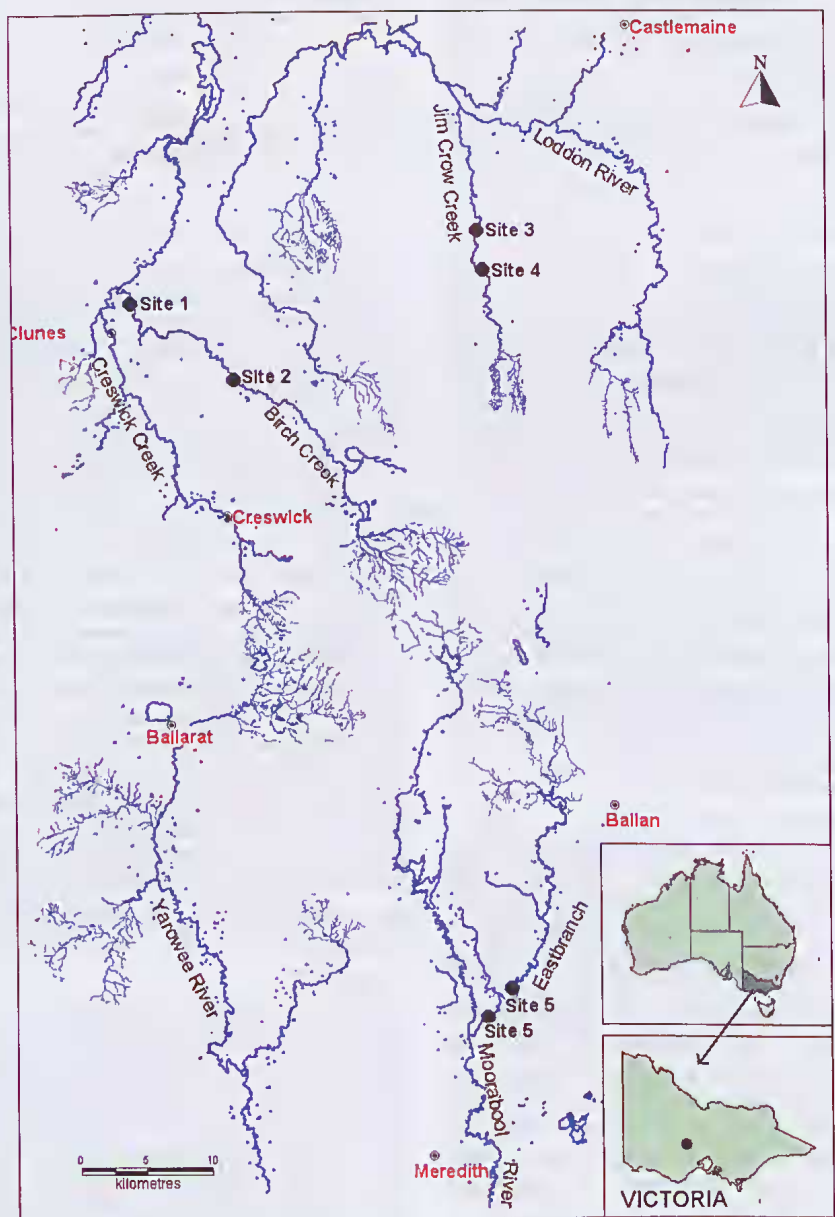


Fig. 1. Sampling sites of Birch Creek, Jim Creek and Moorabool River

Analysis of Principle Co-ordinates (CAP). This technique allows (i) testing for differences among assemblages (ii) identification of taxa most highly associated with the effects of habitats (iii) visualisation of the between and within group variation and (iv) a discriminant analysis (Anderson and Willis 2003; Anderson and Robinson 2003).

CAP analysis of communities was conducted in two ways. First, discriminant analysis was conducted to discriminate between habitats (willow and bare banks) for each river during different seasons. Confusion tables ([mis] classification rates) were also generated. Secondly, CAP was used to determine taxa associated with each habitat type. For that, CAP analysis was conducted for two habitats using the data pooled across three rivers in each season separately. The taxa highly associated with habitat type were identified using correlation between the individual taxon abundance and the canonical axis separating habitats. To calculate the mean correlation value for each taxon, these correlations were averaged across seasons. To examine the community gradients, Principle Coordinates Analysis (PCoA) (Gower 1966) was employed and indirect ordination plots were generated. Both CAP and PCoA were conducted using the CAP package developed by Anderson (2003). In all cases, the Bray-Curtis dissimilarity coefficient was used.

## Results

### *Physical and chemical parameters associated with sampling sites*

The physical and chemical characteristics of sites are summarised in Fig. 2. Flow occurred in all three rivers during winter and spring but there was very little or no flow throughout summer and autumn. Bank habitats had higher flow than willow root habitats during winter and spring when average river flow was highest. Percentage CPOM amount in willow root habitats were higher than in bare bank habitats throughout all seasons. Percentage FPOM showed the same trend within two of the three rivers. Slightly lower dissolved oxygen levels were recorded in willow root habitats during summer and autumn seasons. Slight reduction in temperature was detected in willow root habitats during summer. Conductivity and pH did

not show significant variation between habitats; however, these parameters varied significantly across seasons, rivers and sites.

### *Effect of habitat on macroinvertebrate taxa richness, abundance, biomass and diversity*

There was a significant effect of habitat on species richness and log abundance ( $p > 0.05$ ) but this was not consistent across the different rivers during different seasons of the year ( $p < 0.05$  for season  $\times$  river  $\times$  habitat three-way interaction). Therefore, analysis was carried out separately for the different rivers and seasons. Willow root mats had higher species richness for most sites in all seasons. Total abundance of taxa showed a similar trend (Figs 3a and 3b).

Macroinvertebrate biomass also differed significantly ( $p < 0.05$ ) between the two habitats. In all seasons, macroinvertebrate biomass was higher in willow root habitats (Fig. 3c).

### *Shannon Diversity Index (SDI)*

SDI also showed significant differences between habitats ( $p < 0.05$ ). However, a significant river  $\times$  habitat and season  $\times$  habitat interaction also was observed in the analysis. Therefore, analyses were conducted separately for the different rivers during different seasons. Pair-wise comparisons indicated an inconsistent pattern of SDI between the two habitats during different seasons (Fig. 3d).

### *Effect of habitat on macroinvertebrate community assemblages*

Willow root habitats and bare bank macroinvertebrate community assemblages showed significant differences ( $p < 0.05$ ) in all sites between seasons. Correlations of taxa with canonical axes showed that eight taxa were associated with willow root mats (mean correlation coefficient  $> 0.2$ ). Ten taxa were moderately associated with root habitat (mean correlation coefficient  $> 0.1$ ) (Table 1).

In contrast, four taxa were associated with bare bank habitats (correlation coefficient  $> 0.2$ ) and ten taxa were associated with bare bank habitats (correlation coefficient  $> 0.1$ ) (Table 1).

## Discussion

The differences in physico-chemical parameters associated with willow roots and bare bank habitats can be explained by the structural differences of the two habitats. Flows recorded

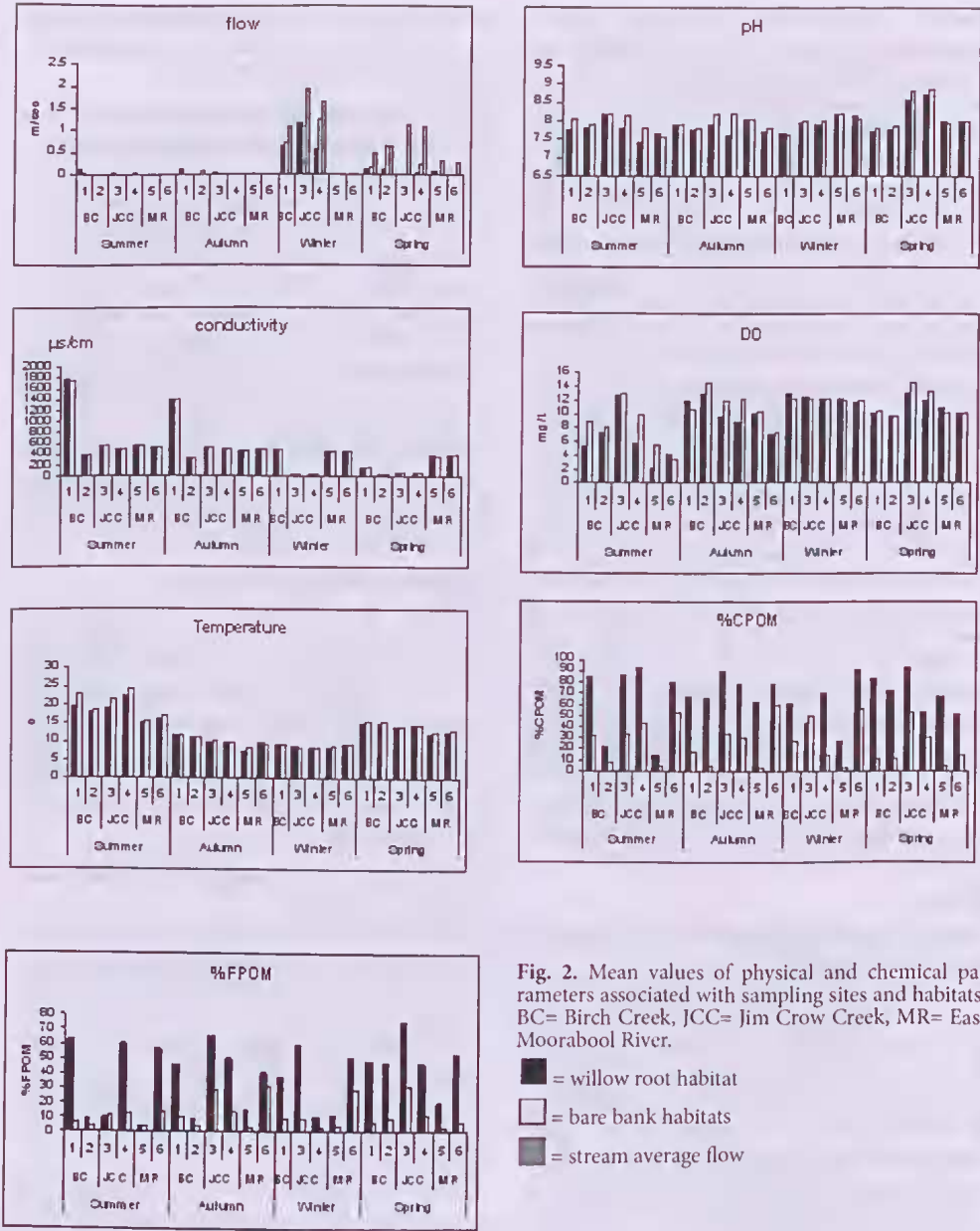
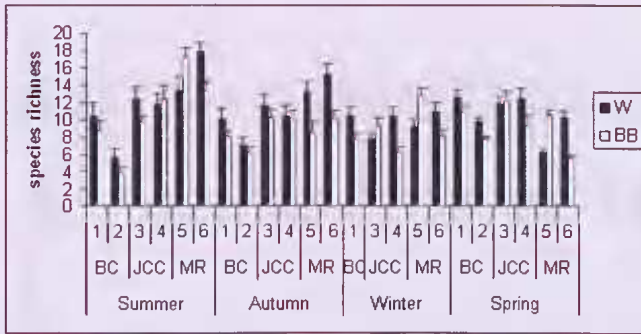
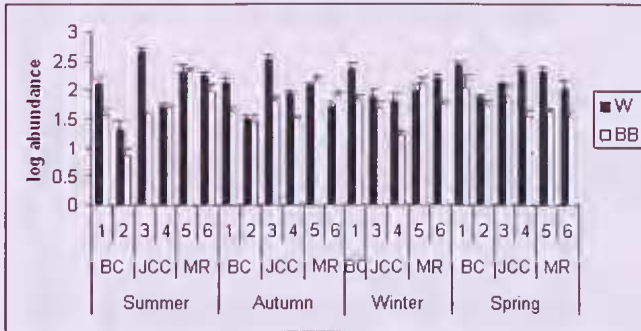


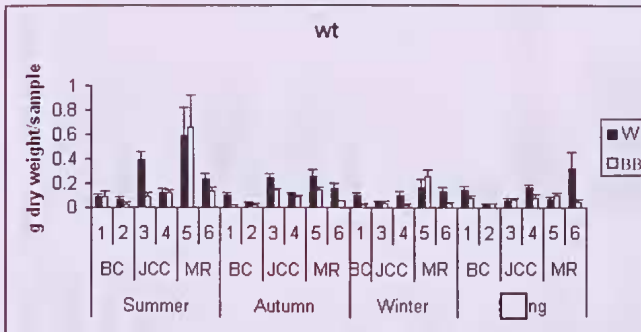
Fig. 2. Mean values of physical and chemical parameters associated with sampling sites and habitats. BC= Birch Creek, JCC= Jim Crow Creek, MR= East Moorabool River.



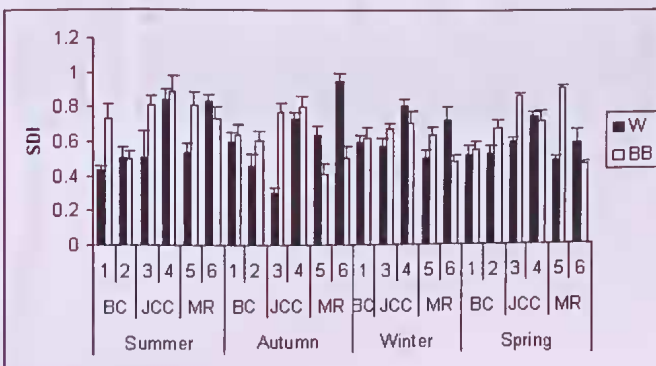
(a)



(b)



(c)



(d)

Fig. 3. Mean  $\pm$  SE of (a) species richness, (b) log abundance, (c) Biomass, and (d) SDI of macroinvertebrates, associated with willow root habitats and bare bank habitats during four seasons of the year.

■ = willow root habitat  
□ = bare bank habitats

Table 1. Taxa association with willow root habitats and bare banks from CAP analysis. (Values indicate correlation coefficient of taxa with canonical axis, blank space = taxon not recorded; positive values indicate a location of willow root habitats and negative values a location of bare bank habitats)

Habitat	Taxa		Summer	Autumn	Winter	Spring	Mean
	Family	Genus/Species					
willow roots	Ceinidae	<i>Austrochiltonia sp.</i>	0.38	0.31	0.27	0.49	0.36
	Coenagrionidae		0.23	0.23	0.29	0.41	0.29
	Talitridae		0.01	-	-	0.29	0.29
	Planorbidae	<i>Gyraulus sp.</i>	0.01	0.31	0.35	0.42	0.28
	Lymnaeidae	<i>Glyptophysa sp.</i>	0.05	0.25	0.29	0.4	0.25
	Paramelitidae	<i>Antipodens sp.</i>	0.3	0.36	0.23	0.08	0.24
	Hydrobiidae	<i>Potamopyrgus sp.</i>	0.16	0.31	0.02	0.36	0.21
	Parastacidae	<i>Cherax destructor</i>	0.26	0.19	0.14	0.23	0.2
	Ephydriidae		-	0.2	-	-	0.2
		<i>Cura sp.</i>	0.09	0.24	0.11	0.31	0.19
	Leptophlebiidae	<i>Atalophlebia australis</i>	0.05	0.21	0.2	0.27	0.18
	Lymnephilidae	<i>Sp b</i>	-	0.14	0.21	-	0.17
	Cordulidae		0.19	0.27	0.1	0.09	0.17
	Lymnephilidae	<i>Sp c</i>	-0.01	0.24	0.13	0.28	0.16
	Syrphidae		-	-	0.15	-	0.15
	Aeshnidae		0.21	0.06	0.16	0.18	0.15
	Hydropsychiidae		0.1	0.18	0.13	-	0.14
	Physidae	<i>Physa acuta</i>	0.11	0.38	0	0.05	0.14
	Simuliidae		0.1	0.03	0.22	0.18	0.13
	Scirtidae	<i>Scirtes sp.</i>	0.03	0.26	0.12	0.11	0.13
	Ecnomidae	<i>Ecnomus sp.</i>	0.02	0.08	0.24	0.08	0.11
	Velidae		0.16	0.04	-	0.12	0.1
	Leptoceridae		0.22	-0.05	0.03	0.18	0.1
	Leptophlebiidae	<i>Neboissophlebia sp.</i>	0.06	-	-	0.13	0.09
	Polycentropodidae		0.09	-	-	-	0.09
	Megapodagrionidae		-	0.08	-	-	0.08
	Lymnephilidae		-0.03	0.04	-	0.23	0.08
	Haplotoxidae		-	-	0.08	-	0.08

Table 1. cont'd

Habitat	Taxa		Summer	Autumn	Winter	Spring	Mean
	Family	Genus/Species					
	Elmidae (larvae)		0.03	0.23	0.04	0.01	0.08
	Calamoceratidae		0.1	0.05	-	0.06	0.07
	Planorbidae		0.03	0.1	-	-	0.07
	Megadrili	<i>Pygmaeus sp.</i>	0.05	0.24	-0.09	0.06	0.06
	Hydrobiidae		0.1	0.2	0	-0.04	0.06
	Tanypodinae	<i>Potamopyrgus sp.</i>	0.07	0.16	-0.1	0.12	0.06
	Caenidae		0.02	-	-	0.1	0.06
	Gomphidae	<i>Tasmanocaenis sp.</i>	0.06	-	-	-	0.06
	Petaluridae		0.06	-	-	-	0.06
	Leptoceridae		0.15	-0.04	0.05	-	0.05
	Elmidae (adult)	<i>Triplectidus sp.</i>	-0.15	0.22	0.07	-	0.05
	Janiridae		0.09	-0.03	0	0.13	0.05
	Halipidae		0.05	-	-	-	0.05
	Hydroptilidae	<i>Halipus sp.</i>	-0.19	0.05	0.14	0.18	0.05
	Odontoceridae		0.06	0.22	-0.13	0.02	0.04
	Leptoceridae		-	0.04	-	-	0.04
	Leptophlebiae	<i>Oecetes sp.</i>	0.03	-	-	-	0.03
	Atriplectidae	<i>Thrausus sp.</i>	0.1	0.05	0.03	-0.06	0.03
	Gripopteridae	<i>Atriplectides sp.</i>	-0.02	-0.18	0.01	0.31	0.03
	Chironominae	<i>Leptoperla sp.</i>	0.16	0.04	0.16	-0.20	0.02
	Dytiscidae		-0.01	0.14	-0.01	-0.02	0.02
	Caenidae	<i>Rhantus sp.</i>	0.17	-0.15	0.15	-0.08	0.02
	Leptophlebiae sp.	<i>Wundacaenis sp.</i>	-0.06	0.1	-	-	0.02
	Glossiphoniidae		0.02	0.1	0	-0.03	0.02

Table 1. cont'd

Habitat	Taxa		Summer	Autumn	Winter	Spring	Mean
Family	Genus/Species						
Bare banks	Sphaeriidae	<i>Sphaerium</i> sp.	-0.03	-0.44	-0.23	-0.29	-0.25
	Psephenidae	<i>Sclerocyphon</i> sp.	-0.37	-0.03	-	-0.27	-0.22
	Empididae		-0.22	-	-	-	-0.22
	Tubificidae	<i>Branchiura sawerbyi</i>	-0.02	-0.41	-	-	-0.21
	Tubificidae	<i>Sp.</i>	0.2	-0.37	-0.41	-0.2	-0.2
	Corixidae	<i>Micronecta</i> sp. (nymph)	-0.37	-0.08	-	-0.06	-0.17
	Lymnephilidae	<i>Sp. d</i>	-0.03	-	-0.26	-	-0.15
	Phreodrilidae	<i>Antarctodrilus proboscidae</i>	-	-0.26	-0.04	-	-0.15
	Siponotidae		-	-0.14	-	-	-0.14
	Ancylidae	<i>Ferrissia</i> sp.	-0.43	-0.07	0.1	-0.14	-0.14
	Sphaeriidae	<i>Pisidium</i> sp.	0.07	-0.17	-0.13	-0.28	-0.13
	Tipulidae		-0.03	-	-0.29	-0.06	-0.13
	Capillariventridae		-	-0.12	-	-	-0.12
	Dytiscidae	<i>Necterosoma</i> sp.	-0.11	-0.05	0.07	-0.35	-0.11
	Leptophlebiae	<i>Atalophlebia australis</i>	-0.1	-	-	-	-0.1
	Lumbriculidae	<i>Lumbriculus variegatus</i>	0.06	-0.14	-0.13	-0.2	-0.1
	Psychridae		-0.1	-	-	-	-0.1
	Corbiculidae		-	-0.13	0	-	-0.07
	Baetidae		0.04	-0.16	-0.19	0.03	-0.07
	Phreotoicidae		0.06	0.04	-0.11	-0.22	-0.06
	Ceratopogonidae		0	-0.07	0.08	-0.24	-0.06
	Corixidae	<i>Micronecta</i> sp. (adult)	0.05	-0.23	0.22	-0.23	-0.05
		<i>Symphitoneuria</i> sp.	-	-	-0.04	-	-0.04
	Dytiscidae (larvae)		-0.02	-0.05	-0.03	-0.07	-0.04
		<i>Leichhard</i> sp.	-0.04	-	-	-	-0.04
	Lymnaeidae	<i>Glyptophysa</i> sp.	0.03	-0.1	-	-	-0.03
	Atyidae	<i>Paratya australiensis</i>	0.06	-0.1	-0.24	0.14	-0.03
	Odontoceridae	<i>Sp. a</i>	0.08	0.12	-0.05	-0.21	-0.02

Table 1. cont'd

Habitat	Family	Taxa	Genus/Species	Summer	Autumn	Winter	Spring	Mean
	Salidae			0.13	-0.18	-	-	-0.02
	Lymanaeidae		<i>Glyptophysa smooth</i>	-0.04	0.05	-0.06	-0.04	-0.02
	Lestidae		<i>Austrolestes analis</i>	-0.02	-	-	-	-0.02
	Notonectidae		<i>Enithares sp.</i>	-0.22	0.05	-0.02	0.12	-0.02
	Brentidae		<i>Berosus sp.</i>	-	-	0	-	0
				-0.01	-	-	-	-0.01

in willow root habitats during winter and spring were comparatively lower than in bare bank habitats in most sites sampled, suggesting that willow roots would act as mechanical barriers and filter suspended material. Higher amounts of CPOM and FPOM occurred in willow root habitats compared to bare bank habitats, even in winter when willows had lost their leaves, further confirming that willow root mats filter suspended material. The relatively reduced temperature levels recorded in willow habitats in summer would be due to the shading effects of the canopy (Pidgeon 1978; Glova and Sagar 1994). The lower dissolved oxygen levels of willow root habitats during summer and autumn can be related to the increased levels of organic matter coupled with reduced stream flow in these seasons. Increased community respiration coupled with reduced dissolved oxygen levels associated with stagnant water created an oxygen gradient between the two habitats. This also could have been affected by the heavy shading of willow habitats during summer and autumn as willows would have had a full canopy that would have reduced the photosynthetic algal growth under willows compared to open bank habitats (Pidgeon 1978; Glova and Sagar 1994).

The interaction of season, river and habitat on species richness and abundance indicates that the effect of habitat is not consistent in different rivers during the different seasons. These differences may be due to inherent heterogeneity of available resources or patchiness of each river, and governed by their flow regimes. Willow root habitats are more favourable for macroinvertebrates in terms of food availability and refuges compared to mineral substrate. Similarly willow root mats act as mechanical barriers, which prevent the effects of high flow and stabilise structures for their attachment compared to the more unstable mineral substrates. Total abundance of taxa showed inconsistent patterns from site to site, probably due to the different compositions of taxa in different habitats. Some micro levels of physico-chemical parameters favour the abundance of particular taxa, which leads to their dominance, creating more variability in total abundance between sites. Besley (1992) compared riparian root habitats of River Red Gum *Eucalyptus camaldulensis*, River Oak *Casuarina cunninghamiana*, and White Willow *Salix alba* with bare bank habitats and showed that riparian root habitats supported significantly more species than bare bank habitats during autumn and

winter. Results of the present study were consistent with these findings.

Total biomass of taxa was consistent in willow root habitats and bare bank habitats during all seasons and rivers, although higher biomass of taxa was observed in willow root habitats in all seasons. Glova and Sagar (1994) showed higher species richness, total abundance and biomass of benthic invertebrates associated with willow than non-willow sections, consistent with our results. The increase of fish abundance associated with willow habitats in the previous study may be attributed to the higher food levels associated with willow habitats.

SDI is more affected by the presence and abundance of taxa. Lowered levels of SDI in willow root habitats in some sites indicate that few taxa dominate that habitat. This suggests that willow root mats favour particular taxa and their abundance. Organic matter enrichment in willow root habitats favours pollution tolerant taxa by replacing more sensitive taxa groups (Suter 1990). Fauna of willow root mats was dominated by deposit feeding collectors such as Oligochaetes and Amphipoda (Latta 1974). Plecoptera, Trichoptera and Ephemeroptera, which respire with gills or direct cuticular exchange, can be particularly susceptible to lowered dissolved oxygen levels (Dallas and Day 1993) and the taxa which were missing from willow sites in summer were consistent with this pattern.

Most taxa showed higher association with willow root habitats during autumn when most of the allochthonous organic matter in the form of food from willow reaches the stream. The differences in community assemblages observed in the two habitats can be related to many factors. Amphipoda (Paramelitidae), a relatively large group of shredders, was the dominant group in willow root habitats in all seasons and were highly associated with willow root habitats during autumn, suggesting an association with CPOM content. Ceinidae were highly associated with willow root habitats during most of the seasons suggesting that they are dependent on FPOM or decaying root mats or have a structural preference for this habitat. The higher association of more organic pollution tolerating taxa, such as *Potamopyrgus* sp., *Cura* sp., Megadrilli, *Physa acuta* and shredders such as Amphipoda, with willow root habitats during autumn in this

study suggests that they prefer organic matter enrichment available from willows during autumn. The higher association of ambush predators, such as Coenagrionidae, with willow root mats suggests that predators also benefit from the complex structures of root mats.

*Simulium* sp. and *Leptoperla* sp. showed moderate mean correlations during winter and spring. *Simulium* sp. uses cephalic fans for capturing food items and may prefer the higher flows of winter, which facilitate its food capturing habit. *Leptoperla* sp. was also highly associated with willow roots during winter and spring. Its preference for this habitat may be related to well-oxygenated fine particulate organic matter in the rich willow root environment. Some grazers, such as *Gyraulus* sp., *Glyptophysa* sp., *Potamophyrus* sp., were associated with willow root habitats during winter and spring, benefiting from periphyton and biofilm associated with willow root mats under the open canopy of willows and from the stable substrate of willow root mats, which provide refuge during high flow.

In contrast, *Sphecarium* sp., Psephanidae, Tubificidae, Corixidae, Phreodrilidae, Ancylidae, *Pisidium* sp., Tipuliidae, Capilariventridae, Dytiscidae Lumbriculidae, and Leptophlebiidae were highly associated with open bank habitats. Their association with mineral substrate may be related to their food acquiring behaviour. Most of them are filter collectors, which benefit through such mineral substrate and associated suspended organic matter. Some predators such as Corixidae and Dytiscidae are also associated with bare bank habitats.

This evidence suggests that willow root mats are productive habitats compared to open bank mineral substrates. This habitat supported distinct macroinvertebrate communities and higher species richness and biomass compared to bare bank habitats. This suggests that removal of willows from streams where other riparian cover is lacking can have detrimental effects on stream macroinvertebrate communities. Boulton and Lloyd (1991) suggest the need of alternative mechanisms to improve habitat heterogeneity where willow removal takes place. Further research is needed to understand alternative methods, such as macrophytes, snags or fast growing vegetation cover, e.g. reeds, would all be effective in improving habitat heteroge-

neity and thus biodiversity in streams where willow removal is taking place.

## References

- Anderson MJ (2003) CAP: a FORTRAN computer program for canonical analysis of principal coordinates. (Department of Statistics, University of Auckland, New Zealand)
- Anderson MJ and Robinson J (2003) Generalised discriminant analysis based on distances. *Australian and New Zealand Journal of Statistics* 45, 301–318.
- Anderson MJ and Willis TJ (2003) Canonical analysis of principle coordinates: a useful method of constrained ordination for ecology. *Ecology* 84, 511–525.
- Bell JD, Steffe AS and Westoby M (1985) Artificial seagrass: How useful is it for field experiments on fish and macroinvertebrates? *Journal of Experimental Marine Biology and Ecology* 90, 171–177.
- Bell JD, Westoby M and Steffe AS (1987) Fish larvae settling in seagrass: Do they discriminate between beds of different leaf density? *Journal of Experimental Marine Biology and Ecology* 111, 133–144.
- Besley CH (1992) Macroinvertebrate assemblages in the riparian tree roots of the Murrumbidgee River NSW. (Unpublished BSc (Hons) Thesis, Charles Sturt University, Wagga Wagga)
- Borchardt D (1993) Effects of flow and refugia on drift loss of benthic macroinvertebrates: implications for habitat restoration in lowland streams. *Freshwater Biology* 29, 221–227.
- Boulton AJ and Lloyd LN (1991) Macroinvertebrate Assemblages in Flood Plain Habitats of the Lower River Murray, South Australia. *Regulated Rivers: Research and Management* 6, 183–201.
- Burchmore JJ, Pollard DA, Bell JD, Middleton MJ, Pease BC and Matthews J (1985) An ecological comparison of artificial and natural rocky reef fish communities in Botany Bay, New South Wales, Australia. *Bulletin of Marine Science* 37, 70–85.
- Cranston P (1996) *Identification guide to the chironomidae of New South Wales*. Australian Water Technologies (AWT) identification guide No.1. (AWT Pty Ltd: NSW, Australia)
- CSIRO (1999) *Interactive guide to Australian Aquatic Invertebrates*. CD ROM. 2 edn. (CSIRO Publishing: Collingwood, Victoria)
- Dallas HF and Day JA (1993) *The effect of water quality variables on riverine ecosystems: A Review*. (No. TT 61/93, Water Research Commission, Pretoria)
- Glova GJ and Sagar PM (1994) Comparison of fish and macroinvertebrate standing stocks in relation to riparian willows (*Salix* sp.) in three New Zealand streams. *New Zealand Journal of Marine and Freshwater Research* 28, 255–266.
- Gooderham J and Tsyrlin E (2002) *The waterbug book: a guide to the freshwater macroinvertebrates of temperate Australia*. (CSIRO Publishing: Australia)
- Gower JC (1966) Some distance properties of latent root and vector methods used in multivariate analysis. *Biometrika* 53, 325–338.
- Harper DM, Smith CD and Barham PJ (1992) Habitat as the building blocks for river conservation assessment. In *River conservation and Management*, pp 311–319. Eds PJ Boon, P Calow and GE Potts. (John Wiley and Sons Ltd: Chichester)
- Hawking JH and Theischinger G (1999) *Dragonfly larvae (Odonata): a guide to the identification of larvae of Australian families and to the identification and ecology of larvae from New South Wales*. Australian Water Technologies (AWT) identification guide No.3 and Cooperative Research Centre for Freshwater Ecology (CRCFE) identification guide No. 24. (CRCFE: Albury and AWT Pty Ltd: West Ryde, NSW)
- Jayawardana JMCK (2011) Littoral macroinvertebrates in relation to native and exotic riparian vegetation in streams of central Victoria, Australia. *International Journal of Energy Environment and Economics* 19, 635–655.
- Jayawardana JMCK and Westbrooke M (2010) Effects of riparian vegetation changes on functional organisation of macroinvertebrates in central Victorian streams, Australia. *The Victorian Naturalist* 127, 36–46.
- Koehn JD (1987) Artificial habitat increases abundance of two-spined blackfish (*Godopsis hispidus*) in Ovens River, Victoria. Technical Report Series No 56 (Arthur Rylah Institute of Environmental Research, Melbourne)
- Ladson A, Gerrish G, Carr G and Thexton E (1997) *Willows along Victorian waterways. Towards a management strategy*. (Waterways Unit, Department of Natural Resources and Environment, Victoria)
- Langler GJ and Smith C (2001) Effects of habitat enhancement on 0-group fishes in a lowland river. *Regulated rivers: Research & management* 17, 677–686.
- Latta IK (1974) Some effects of willow (*Salix fragilis*) on New Zealand streams and their faunas. (Unpublished MSc Thesis, University of Otago, Dunedin, New Zealand)
- Minshall GW (1988) Stream ecosystem theory: a global perspective. *Journal of North American Benthological Society* 7, 263–288.
- Minshall GW and Robinson CT (1998) Macroinvertebrate community structure in relation to measures of lotic habitat heterogeneity. *Archiv fuer Hydrobiologie* 141, 129–151.
- Phillips EC and Kilambi RV (1994) Use of coarse woody debris by diptera in Ozark streams, Arkansas. *Journal of North American Benthological Society* 13, 151–159.
- Pidgeon RWJ (1978) Energy flow in a small stream community: an evaluation of the effects of different riparian vegetation. (Unpublished PhD thesis, University of New England)
- R- Development Core Team (2004) R: A language and environment for statistical computing. (R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org>)
- Robertson D (1993) *Interactions between riparian vegetation and macrobenthic animals of the Murrumbidgee River*. (Inland and Water Resources Research and Development Corporation Special Research and Development Project, Charles Sturt University, Wagga Wagga)
- Russell BC (1976) Man made reef ecology; a perspective view. In *Proceedings of the First Australian Conference on Artificial Reefs, Brisbane, Queensland, September 1975*. Ed P Saege. (Australian Underwater Federation, Brisbane)
- Schiemer E, Spindler T, Wintersberger H, Schneider A and Chovanec A (1991) Fish fry associations: important indicators for the ecological status of large rivers. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 24, 2497–2500.
- Suter PJ (1990) *The effects of willows on river ecology*. Paper prepared for the Murray-Darling Association. (Office of the Environmental Protection Authority, Adelaide)
- Talbot FH, Russell BC and Anderson GRV (1978) Coral reef fish communities: Unstable, high diversity systems? *Ecological Monographs* 48, 425–440.
- Yeates LV (1994) The role of invertebrates and microorganisms in the breakdown of willow and eucalypt leaves in a Tasmanian stream. (Unpublished BSc (Hons) Thesis, University of Tasmania)
- Yeates LV and Barmuta L (1999) The effects of willow and Eucalypt leaves on feeding preference and growth of some Australian aquatic macroinvertebrates. *Australian Journal of Ecology* 24, 593–598.
- Young K (1980) *Soil conservation protects the trout*. (Soil and water 7–8)

Received 24 July 2014; accepted 12 March 2015